PATENT SPECIFICATION

607,701

Application Date: Sept. 14, 1945. *No. 23704/45.*

Complete Specification Accepted: Sept. 3, 1948.

Index at acceptance:—Classes **72,** B1b1; **and 83(ii),** A85.

COMPLETE SPECIFICATION

Method of Manufacturing Annular Alloy-steel Articles such as Piston Rings

I, HARRY MORTON BRAMBERRY, a Citizen of the United States of America, a resident of 100 Leland Street, New Castle, Henry County, Indiana, United States of America, do hereby declare the nature of this invention, and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

This invention relates to the manufacture from nitridable alloy steels of piston rings, or other annular articles having a small cross-sectional dimension, and which grow during the nitriding process. It is the primary object of the invention to provide a method and apparatus for forming a nitrided case on such articles which will utilize the growth of the article during the nitriding process to prevent undesired distortion of the article and to cause it to assume the final, desired shape. The invention is useful only in the manufacture of articles from a steel alloy having the characteristics referred to, and wherever in this application reference is made to the material of which the articles are to be formed it will be understood that such a steel alloy is referred to.

Possibly the most important current application of my invention is in the manufacture of piston rings, and hence, I will give a detailed description of this method of piston ring manufacture as it is actually being successfully practised in the fabrication of piston rings for military aircraft engines and engines for other equipment. It will be understood, of course, that this is by way of preferred example, it being apparent that a wide variety of other articles may be fabricated in a like or equivalent manner coming within the broad scope of my invention.

I am aware that much previous work has been done in an effort to properly nitride, shape and otherwise process articles of small cross-sectional dimension. However, the particular technique or method herein presented is believed to be new.

Prior to the present invention, it is not believed that an article of small cross-sectional dimension—such, for example, as a piston ring—was ever satisfactorily made from alloy steel by subjecting the same to a nitriding treatment without the occurence of such excessive distortions as to require the removal of practically all of the effective nitrided case in certain areas in order to finish-machine the article to the required dimensions. While I found that nitriding an alloy steel article of small cross-sectional dimension provided the same with the requisite case thickness and wear characteristics—as, for example, in providing the wearing surfaces of a piston ring—I also found that this same nitriding process caused so much distortion in the contour of the ring as to necessitate the removal of such a critical proportion of the case thickness as to approach dangerously close to the underlying core structure in certain areas. Prior to the present invention, it has been found that in a high percentage of the resulting rings or other nitrided alloy steel articles of small cross-sectional dimension, the necessary removal of stock in order to produce uniform dimensions has resulted in actually cutting critically into the case, which, of course, renders that article or ring completely unsatisfactory.

It is a well-known fact that aircraft engine builders have been confronted with increased power requirements year after year. Such increased power output has resulted in tremendous piston ring loads, so much so, that the piston ring constitutes the limiting factor with respect to further power increase if the same is to be realized without suffering an appreciable reduction in life and efficiency. To meet the increased power requirement and eliminate the piston ring as being the

[*Price* 1/-]

"bottle-neck" to further development, it was necessary to adopt new and reduced piston ring proportions, especially a much reduced cross-sectional area. Alloy steel has been found to meet the requirements, provided the load-carrying surfaces can be so treated as to give a surface, as well as case and core structure that can be loaded to the maximum without the attendant scuffing, scoring and non-compatible condition experienced with the general run of quenched and drawn steels.

It is, of course, known that alloy steel rings as well as cast iron rings may be plated by the chrome process to provide a wear surface with a degree of success. There are, however, a number of disadvantages which render this process incapable of producing rings which will operate under the severe conditions in which the rings of the present process are called upon to operate. In the first place, one of the most serious weaknesses in the small section article such as a piston ring treated in accordance with this known chrome process is the resulting hydrogen embrittlement. Also, extreme difficulty is encountered in effecting a uniformly distributed thickness of chrome plate. In addition, when operated under dusty conditions, the plating soon wears away, which immediately results in non-compatible load-carrying surfaces. Therefore, chrome plated rings find limited usefulness where conditions are not as severe as those conditions under which it is contemplated that the present rings must operate.

It is an object of this invention to provide a method of fabricating annular alloy steel articles of small cross-sectional dimension—particularly alloy steel piston rings—of a selected steel having the property of growing when nitrided and taking advantage of this growth to produce a desired size and shape without distortion.

It is another object of this invention to provide an improved method and technique of nitriding annular alloy steel articles of small cross-sectional dimension—particularly piston rings of small section—wherein the contour of the structure is preserved or held in such a manner as to prevent the occurrence of distortions normally resulting from such nitriding process.

It is a more detailed object of the present invention to provide a nitriding furnace fixture uniquely adapted by virtue of its structural features of the performance of the herein contemplated process, particularly as applied to the fabrication of alloy steel piston rings.

According to the invention, the method of manufacturing a piston ring, or other annular article having a small cross-sectional dimension, from a nitridable alloy steel which grows during the nitriding process, consists in forming a blank of the same shape but of smaller diameter than the final article, confining the blank in a furnace fixture having a shape and diameter corresponding to that of the final article, subjecting the blank to a nitriding atmosphere at a selected temperature and for a selected time so as to form a nitrided case on the blank, employing the growth of the blank to exert pressure against the fixture so as to prevent distortion of the article, and then removing the blank from the fixture.

As applied to the manufacture of a Nitralloy "N" piston ring from a split, normally circular piston ring blank, the method comprises confining the blank within a furnace fixture which is larger in circumference than the blank, spreading the free ends of the blank sufficiently that when the blank is nitrided it will expand against the fixture, uniformly subjecting all surfaces of the blank to heat and a nitriding atmosphere at a temperature below the critical temperature of the Nitralloy "N," utilising the growth property of the metal due to nitriding thereof to effect radial engagement with the interior of the fixture whilst the nitrided case is being formed, and removing the blank from the fixture.

The furnace fixture for carrying out the method according to the invention may comprise a female furnace form provided with an internal contour corresponding to the external periphery of the article to be nitrided therein but permitting introduction of the article therein prior to nitriding, the fixture being adapted to resist the pressure exerted by the growth of the article to preserve the contour of the latter against distortion, said fixture providing for the release of the article after nitriding.

The invention is described more in detail in the following specification which is accompanied by drawings in which:

Fig. 1 is a plan view of an endless ring blank which is to be heat treated in accordance with the present invention and from which a split piston ring is subsequently to be made by cutting out a section therefrom in the so-called "joint" area;

Fig. 2 is an enlarged view on the line 2—2 of Fig. 1, showing the joint area and the manner of recessing the same prior to heat treatment;

Fig. 3 is an enlarged radial cross-section of a compression ring blank with part of the ring broken away and indi-

cating the uniform composition of the metal and relative size of the section prior to being treated in accordance with the present invention.

Fig. 4 is an enlarged radial cross-section view corresponding to Fig. 3 but showing an oil control ring blank and indicating the substantially uniform composition of the metal prior to the ring being treated in accordance with the present invention;

Fig. 5 is an axial section view of my improved male reshaping furnace fixture form, associated loading ring member, and ring bending tool and guide;

Fig. 6 is a plan view taken substantially on the line 6—6 of Fig. 5 with certain parts removed and others broken away;

Fig. 7 is a plan view taken substantially on the line 7—7 of Fig. 5 showing an endless ring blank in firmly engaged position about the male preshaping form;

Fig. 8 is a view similar to Fig. 7 but showing an endless ring blank bent inwardly in the joint area by means of the bending tool and guide;

Fig. 9 is a broken-away plan view partially in section taken substantially on line 9—9 of Fig. 10 showing the complete furnace fixture with the rings in position firmly engaging the inner male preshaping form and with the outer female nitriding form positioned in embraced relation thereabout and spaced slightly therefrom;

Fig. 10 is an axial section view taken substantially on the line 10—10 of Fig. 9;

Fig. 11 is a view indicating schematically the nitriding furnace with the furnace fixture positioned within the furnace;

Fig. 12 is an enlarged broken-away section view corresponding to a portion of Fig. 10 and showing a group of endless compression ring blanks in close engagement with the wall of the inner male preshaping form prior to the heat treatment;

Fig. 13 is a broken-away cross-section view corresponding to Fig. 12 but showing the position of the endless ring blanks in pressure engagement with the inner peripheral wall of the female nitriding form at the end of the nitriding heat treatment and growth process and indicating generally the case and core relationship in each ring resulting from such treatment;

Fig. 14 is a perspective-like view of the female furnace fixture nitriding form as the same appears after being removed from the furnace following a heat treatment with the ring blanks in position exerting radial pressure against the peripheral wall of the female form requiring the opening of the fastening latch in order to effect the release of the rings;

Fig. 15 is a schematic view of the endless, ring blank holding jig and the grinding wheels for removing the stock at the joint to provide the finished split piston ring;

Fig. 16 is a plan view of a finished piston ring indicated schematically in closed position in the cylinder of an internal combustion or other compression engine;

Fig. 17 is an enlarged cross-section view of a compression piston ring blank, such as shown on a smaller scale in Fig. 13 resulting from treating the blank of Fig. 3, and bringing out to advantage the details of the case and core relationship resulting from the present method of heat treatment;

Fig. 17a is a view corresponding to Fig. 17 but showing the completed ring section after the finishing operations have been performed;

Fig. 18 is an enlarged cross-section view of an oil control ring blank bringing out to advantage the case and core relationship resulting from heat treating the ring of Fig. 4 in accordance with the present nitriding method;

Fig. 18a is a view corresponding to Fig. 18 but showing the completed oil ring section after the finishing operations have been performed;

Fig. 19 is a plan view corresponding to Fig. 9 but showing an alternative arrangement for practising the present invention wherein the ring blank is heat treated in the split condition thereof instead of the endless condition of Fig. 9;

Fig. 20 is an axial cross-section view of an internal combustion engine cylinder barrel or liner blank in position in a nitriding furnace form to be heat treated in accordance with the present invention; and

Fig. 21 is a broken-away section of a gear and nitriding furnace form arranged for heat treating the gear in accordance with the present invention.

The present method involves essentially taking advantage of the growth of nitrided steels such as Nitralloy N, Nitralloy G and Nitralloy modified—G. from which relatively small cross-sectional dimension articles are to be fabricated. It has been found that this growth occurs, for example, when a nitridable alloy steel article of small cross-sectional dimension is subjected to a nitriding atmosphere for a selected temperature and time. By placing the article to be treated in a confining furnace

fixture or form and allowing the article to grow and exert pressure engagement against the confining form, I accomplish the very important result of preserving and setting the contour of the article by preventing the occurrence of the normally present distortions caused by the nitriding treatment.

My invention will first be described by by way of preferred example as applied to the fabrication and heat treatment of an alloy steel piston ring. Referring to Fig. 1, a piston ring blank PRB is shown as comprising an endless circular ring, larger in diameter than the finished ring, to be manufactured, by the amount of the selected length of stock to be subsequently removed and indicated at JSR (joint stock removal). The rings, the manufacture of which is herein described, are those that I have built for the Wright—Aero—R-1820 cyclone engine. The compression ring blank, cross-section of which is shown in Fig. 3, has an initial outside diameter IOD in the rough form of 6.494″ ± .001″, requiring a subsequent joint stock removal JSR of 1.242″ measured on the chord. The oil control ring blank, cross-section of which is shown in Fig. 4, has an initial outside diameter of 6.589″ ± .001″, requiring a subsequent joint stock removal of 1.565″. Referring to Fig. 2, it will be noted that an arcuate concave section CS is removed from each side of the ring blank within the area JSR and a tool and guide locating notch N is formed in the face of the ring centrally of the area JSR. The function of the concave section is to provide a space for the formation of up-set protuberances when the ring is subsequently pushed or bent radially inwardly as will appear. Otherwise, the occurrence of such protuberances would prevent or interfere with the flat contact of adjacent rings when placed side by side in the nitriding fixture to be described.

The initial ring stock or blank for making a compression ring before the same has been treated to provide the important case, core and other physical characteristics is shown in enlarged cross-section in Fig. 3. The section is indicated as being substantially uniform in structural composition throughout. The compression ring initial radial thickness CIRT is 0.1525 ± .0005″ when made of drawn wire. The compression ring initial width CIW after roughing of the sides to provide for gas circulation is .0715″ ± .0005″. In other works, the desired surface roughness is effected by honing or grinding each side to provide for the requisite circulation of gas between adjacent rings while in the furnace fixture as will appear. The corners of the blank are rounded with a radius CR of 0.012″ to 0.015″.

In Fig. 4 there is shown an enlarged cross-section of an oil control ring blank before the same has been treated to provide the important case, core and other physical characteristics. This section is likewise indicated as being substantially uniform in structural composition throughout. The oil ring initial radial thickness OIRT is 0.1725″ ± .0005″ while the oil ring initial width OIW is .0715″ ± .0005″ after roughing of the sides to provide for gas circulation as above described. The inside corners of the blank are likewise given a radius ORI of .012″ to 0.015″ while the face portion is initially defined by a pair of converging sides OCS terminating in a centrally disposed arcuate initial face portion OIF. The sides OCS are tangent with arcs of radius ORO of 0.010″ defining the oil ring outside corners joining the parallel ring sides. The converging sides OCS are also tangent with the initial face arc portion OIF which has a radius of 0.010″.

Turning now to the nitriding process and referring particularly to Figs. 5 and 14, the endless circular ring blank PRB (either a compression ring blank or oil ring blank) is first pressed over a ring guide 10 by a reciprocable loading tool 11 leading to a male preshaping form 12 of the nitriding furnace fixture indicated generally at 13 (Fig. 10 and 11). This male preshaping member 12 is out of round in plan section, simulating the shape of the final split piston ring in its free condition, and is normally referred to as being parabolic-like in shape. Various methods are known for arriving at and preparing this shape, any one of which may be employed.

Next, the ring blank PRB is pressed or bent inwardly in the area opposite the joint stock removal portion JSR by means of a suitable tool 14. The male preshaping form 12 is provided with a flat portion 15 and the ring blank is bent inwardly with reference thereto (Figs. 6 to 8), to provide for resilient action of the ring blank and to effect conformity of the inner periphery of the ring blank against the preshaping male form. Also of importance is the fact that this prevents fatal distortion thereof which would otherwise result from forcing the same about a male preshaping form not provided with such flat portion. This preshaping male form 12 is given a concentric shape to that of the inner periphery of the female form 17 (Fig. 9) but, of course, smaller in order to permit of the introduction of the ring PRB there-

between. With the ring thus in place about the male preshaping form 12 and the female nitriding form 17 placed in embracing relation thereabout (Figs. 9 and 10), there exists a slight clearance between the outer periphery of the ring blank PRB and the inner periphery of the female form 17 around the entire circumference; except in the area JSR opposite the flat portion 15 of the male preshaping form, which is not important since this section of the ring will later be removed. For example, in the present case involving the manufacture of a compression ring having a finished closed ID of 6.125", a final radial thickness of 0.150" and final width of .070", this clearance will be of the order of .004" to .005". This clearance will, of course, be different for different sizes and cross-sections of rings and other articles in order to provide for the proper growth and pressure relationship. Next, the assembly, after being properly fastened together with resilient Belleville washer 18 in position, is subjected to a predetermined nitriding heat cycle in furnace 19 (Fig. 11).

In the present example, I prefer to make the ring of the particular alloy steel known to the trade as Nitralloy "N" because of the unusual properties of this metal and the unexpected manner in which the same responds to the method herein disclosed.

Nitralloy "N" is a commercially available alloy steel.

The composition of Nitralloy "N" comprises—

C (Carbon) - - -	0.20—.27%
Mn (Manganese) -	0.40—.70%
Si (Silicon) - - -	0.30 max.
Al (Aluminium) - -	1.10—1.40%
Cr (Chromium) - -	1.00—1.30%
Mo (Molybdenum) -	0.20—0.30%
Ni (Nickel) - - -	3.25—3.75%

and the balance Iron, except, of course, for impurities. The exact extent to which variations in this composition of Nitralloy may be permissible has not been exactly determined. However, the product supplied, for example, by the Allegheny Ludlum Steel Company, or any of the other sources and specified as conforming with the above composition has, in my experience, been found to produce rings of the desired characteristics. I do not claim any invention in this particular metal alloy *per se* but do claim the herein-disclosed method of manufacturing articles from this alloy; as well as from others having the essential characteristics, e.g. Nitralloy G, Nitralloy Modified—G and alloy steels containing aluminium.

With the furnace fixture containing the rings in position within the furnace 19 as indicated in Fig. 11, the same is first subjected to a purging which comprises blowing gaseous ammonia there through at a relatively high rate and at a soaking temperature of the order of 925 ± 5° F. for a period of about two hours. During this time a heavy ammonia flow is maintained, with the result that ammonia disassociation is prevented as well as preventing the beginning of nitriding action on the ring blank. Of particular importance is the fact that during this soaking period the rings are sufficiently relieved to effect a set in the shape thereof to the shape of the male preshaping form 12 about which the same have been previously introduced. The accomplishment of this shaping and setting is believed to be the result of an improvement in the physical properties of the blank as evidenced by an appreciable increase in Rockwell hardness, which occurs in the nitralloy blank as a direct result of heating in the temperature range of from 900 to 1000° F. This improvement of the physical properties of the nitralloy "N" blank under these conditions appears to be a unique characteristic of this nitralloy "N" and is not present in any other known alloy, at least to this marked degree. The heavy ammonia flow serves the purpose of preventing nitriding and accompanying growth of the blank until the preshaping or setting of the ring blank to the shape of the male form has been accomplished. This preshaping and setting is very important because the male furnace form has a concentric shape to that of the female furnace form. The ring blank having thus been first shaped and set about the male form will subsequently grow away from the male form and into uniform pressure contact with the inner peripheral wall of the female form.

The actual preshaping temperature as well as soaking time employed is a result of experiment in the manufacture of rings and may be varied somewhat depending upon circumstances. It is to be noted, for example, that a somewhat higher temperature such as a temperature of the order of 975° F. approaching more closely the critical or normalizing temperature of 1300° F., would effect a more complete normalizing and setting to shape. Such higher temperature would be accompanied by the growth phenomenon where subjected to ammonia gas and hence would defeat the preshaping and setting to the shape of the male form. Where we subsequently nitride and grow a ring blank away from the male form and into

contact with the female form as herein contemplated, it has been found that the degree of normalizing and setting to shape accomplished at a relatively low temperature of the order of 925° F. is sufficient.

I have found that by carrying this temperature higher in a non-oxidizing atmosphere a somewhat less expensive but less efficient ring may be manufactured suitable for subsequent use in a plating process such as that commonly known as chrome plating. No complete detailed description of the several alternative techniques of preshaping in a non-oxidizing atmosphere without actual growth will be described herein as the present case is primarily directed to the unusual phenomenon of growth in confinement.

Following the above preshaping heating the rings are next subjected to a normal nitriding atmosphere for an additional time period of approximately thirty-five hours at 995° ±5° F. This results in the ring blanks PRB growing away from the male form 12 and into contact with the embracing inner peripheral wall of the concentric female form 17, which is a very important aspect of my invention.

While the above temperature ranges and nitriding time are employed because of the particularly satisfactory results obtained therewith, it will be understood that in the broader aspects of my invention I contemplate other temperatures coming within the nitriding range as well as other nitriding time periods so long as the same are effective to produce the herein disclosed growth in confinement.

By taking advantage of this growth characteristic of the metal under the nitriding conditions and allowing the ring blanks to grow into contact with the embracing female form, a most important result is obtained. The female form 17, being made of substantial cross-section, retains its identical shape, and when the relatively small section ring blanks PRB are made to grow into pressure contact therewith, the surface contour of the ring is thoroughly preserved and the overall shape of the female nitriding form attained by the ring blank resulting in a highly satisfactory ultimate ring, notwithstanding the relatively small section of the blank involved. The furnace fixtures are made of 2330 SAE (Society of Automotive Engineers) steel and are so completely stabilized, as well as protected by electroplated surfaces, that they retain their shape over a long period of operation and many heat cycles.

Particular attention is drawn to an unusual and phenomenal characteristic of Nitralloy "N" when treated as described above. From the very beginning of the heat treatment there occurs an appreciable improvement in the physical properties of the core. This is not true of any other known alloy. In the case of the present ring, this improvement in physical properties of the core is particularly significant in that it makes the core a suitable carrier for the outer hard case.

Referring further to the furnace fixture (Figs. 5 to 14), the ring blanks PRB are held edgewise in a flat parallel condition by a flat and parallel shoulder 22 provided therefor on the male form 12 at one extremity and by a cover 23 at the opposite extremity thereof having thereon a parallel surface 24 in contact with the topmost ring blank. This cover is held or clamped in position by the use of Belleville spring washer 18 having a constant spring rate and being adjusted to the desired pressure by a through bolt 25 and nut 26. The surrounding female form 17 rests on and floats upon the base 27 of the fixture, being provided with positioning means which may be in the form of a pin 28 carried by female form 17 and riding in a radially extending keyway 29. This arrangement allows for the free movement of the female form 17 to adjust itself with reference to the growth of the ring blanks, thus assisting in providing uniform pressure engagement of the ring blanks with the female form throughout the inner circumference thereof. A locking pin 31 passes through the head of bolt 25 and into base 27 preventing relative rotation upon the turning of nut 26.

The female form 17 is preferably composed of a split ring of many times the cross-section of the ring blank or blanks to be grown into radial pressure engagement therewith. I have found that a female form 17 composed of 2330 SAE steel, and nickel plated, is satisfactory for manufacturing the present rings when given a radial thickness of the order of from five to ten times that of the rings to be nitrided therein. The axial width will depend upon the number of rings to be treated in a single heat, the female form 17 shown in Fig. 14 having a width of the order of 2" and having a capacity of twelve rings.

For accurately maintaining the inner peripheral circumference, the ends of the female ring form 17 are provided with a drilled and reamed hole extending in the axial direction, through which the ring is cut at 32 and into which drilled hole is placed a dowel 33. The female ring ends are arranged to be fastened against this

dowel 33 by means of a pivotal latch 34.

When the nitriding treatment has been completed, it will appear that the rings may be readily removed from confinement within the female form 17 by first releasing latch or fastening means 34. This is followed by employing a wrench or wedge inserted in the radially extending slot of the female form 17 for slightly opening the same.

It is particularly important that the nitriding atmosphere be circulated to all of the surfaces of all of the ring blanks substantially uniformly in order that the depth of the resulting nitrided case below the several surfaces may be made substantially uniform. In a piston ring this is important in order to provide the proper physical characteristics including: the proper free joint opening when the section of stock JSR has been removed; the proper radial pressure characteristics including the radial point pressures, that is, radial pressures at the ends of the ring, which pressures must be held within close limits; the proper depth of case below the cylinder wall engaging face; the proper tensile strength, and hence, the proper fatigue characteristics; the proper conformity with the contour irregularities of the cylinder walls at high temperatures and pressures; and full control of flatness. To provide this uniform exposure to the nitriding gases, the inner peripheral wall of female form 17 is fabricated with a plurality of axially extending recessed gas channels 37. These gas channels are of such small circumferential extent as not to make any impression upon the outer periphery or face of the rings when the same exert radial pressure thereagainst. I have found that about 17 of these gas channels 37 having a circumferential length each of about 0.062″ and a depth of about 0.031″ are sufficient to provide ample circulation to the ring blank faces. Particular attention is directed to the fact that the compression ring blanks are formed with a small radius CR of .012″ to .015″ at each extremity of the ring face with the result that adjacent rings define with the inner peripheral wall of the female form-during the final portion of the nitriding—forward gas circulating channels 38 (see Fig. 13).

As pointed out above, the sides of the ring blanks have been given the desired surface roughness providing for gas circulation therebetween.

When the nitriding is first begun and the rings firmly engage the male preshaping form 12, the inner radiused corners CR define with the male form, horizontal circulating channels 39 (see Fig. 12). Male form 12 is likewise provided with axially extending recessed gas channels 42. Base 27 is provided with gas passages 43 communicating with the lower extremities of channels 37 and 42 as well as with a gas passage 44 communicating with the top extremity of passages 37 and 42 through the interior of male form 12 by way of opening 46 and space 47 between male member 12 and cover 23. The spacing 47 provides for firm pressure contact between the top ring and the cover member 23. This is very important in accomplishing the requisite substantially perfect flatness of the resulting rings. This cover is also provided with a gas opening 48. A pin 49 passes through cover 23, male member 12 and base 27 functioning to maintain the proper relation therebetween.

When the endless ring blanks are removed from the female form 17 following the above nitriding growth treatment it is found that a cross-section therethrough presents a very definite structural picture. Referring to Fig. 17, a cross-section of a compression ring is shown as composed of the inner core, the adjacent transition zone CHTZ, and the prime or hard case CHPC and an outer matted layer CHM. The transition zone CHTZ has a general depth of the order of .0035″ to .0065″. The prime hard case CHPC thickness is of the order of .008″ to .011″.

Following the removal of the endless rings from the female form 17 as noted above, the rings are lapped or finish-honed on each side to remove the matted surface CHM and to reach the underlying structure of the prime hard case CHPC removing as little of the latter as is necessary in order to reach a uniform surface. It is found necessary to remove only about .0005″ to .001″ from each side of the ring blank in order to obtain a uniform hard case CPCS having a depth of the order of .007″ to .010″ below the surface on each side.

Next the rings are " set up " to remove approximately 1.242″ from the joint area JSR measured along the outer chord as indicated on Fig. 15. In accomplishing this the rings are held in a fixture 54 while the grinding wheels 55 cut out the requisite sections. Finally the rings are co-directionally finish-honed on the cylinder wall engaging surface to remove the matted layer and to leave as much as possible of the underlying prime hard case. As a result of my process, I am able to leave a prime hard case depth CPCF on the cylinder wall engaging face of the present rings of the order of .0055″ to .0085″, by honing away CY to a depth of only about 0.0025″. A case depth of

.0040″ to .0090″ is within acceptable limits to produce a satisfactory ring, when the inaccuracy of potting up and honing is considered.

Referring now to Figs. 18 and 18a, showing cross-sections of an oil control ring, a similar structural arrangement is presented, the prefix letter O being used to differentiate the oil control ring from the compression ring C. The principal difference is in the cylinder wall engaging surface.

As will be noted from the following comparative analysis of the resulting compression ring and oil ring, the prime hard case of the oil ring in the nose area is somewhat deeper as a result of the particular converging construction of this nose. This is a distinct advantage since the unit pressure of this reduced surface in engagement with the embracing cylinder wall is greater with a consequent slightly increased rate of wear over that which is present in the wider face of the compression ring.

The following gives a comparison of the compression ring blank before nitriding (Fig. 3), after nitriding (Fig. 17) and in the finished form (Fig. 17a);

(1) Compression Ring Blank Initial Outside Diameter - - -	– CIOD – 6.494″ ± .001″
Compression Ring Blank Initial Outside Circumference mounted on male form - - - - -	– CIOC – 20.403″
Compression Ring Blank Initial Radial Thickness - - - -	– CIRT – 0.1525″ ± .0005″
Compression Ring Blank Initial Width when rough finished on sides to provide for gas circulation between sides - - -	– CIW – .0715″ ± .0005″
(2) Compression Ring Blank Nitrided Outside Circumference - -	– CHOC – 20.465″
Inner Circumference of Female Form - - - - - - -	– 20.453″
CHOC (20.465″) minus CIOC (20.403″) - - - - - average growth while confined in fixture	– 0.062″
Compression Ring Blank Nitrided Radial Thickness - - -	– CHRT – 1530″ ± .0005″
CHRT (0.1530″) minus CIRT (0.1525″) - - - - - average growth	= 0.0005″
Compression Ring Blank Nitrided Width - - - - - -	– CHW – .072 ± .0005″
CHW (0.07175″ mean) minus CIW (0.07125″ mean) - - average growth	= .0005″
Compression Ring Blank Nitrided Prime Hard Nitrided Case -	– CHPC – .008″ to .011″
Compression Ring Blank Nitrided Depth of Transition Zone - -	– CHTZ – .0035″ to .0065″
(3) Compression Ring Finished, Cut, Closed, Outside Diameter - -	– CFOD – 6.125″ ± .001″
Compression Ring Finished, Cut, Closed, Radial Thickness - -	– CFRT – .150″ ± .0015″
CHRT (0.153″ mean) minus CFRT (0.150″ mean) - - maximum removed in finishing.	= .0030″

Although this difference is .0030″, we hone a maximum of only .0025″ which still keeps within a finished dimension of .150 ± .0015″.

Thus, in finishing the cylinder wall contacting face of the rings, I remove .002″ to .003″. This portion that is removed is composed of about 0.0005″ of matted surface and a thin portion of the underlying hard nitrided case.

Compression Ring Finished, Cut, Closed, Width - - - - -	–CFW–.070±.0005″
CHW (0.07175″ mean) minus CFW (.070″) - - - - -	=.00175″
mean total removed.	

Thus, in finishing the sides of the ring, I remove about .0009″ from each side. This is composed of about .0005″ of matted surface and the rest of underlying hard, nitrided case.

Compression Ring Finished, Prime Hard Nitrided Case Depth Remaining Below the Face - - - - - - - -	–CPCF–.0055″ to .0085″
Compression Ring Finished, Prime Hard Nitrided Case Depth Remaining Below Each Side - - - - - - - - -	–CPCS–.007″–.010″

The difference in the finished depth of case between the cylinder wall engaging face and the sides is explained by the fact that it is not practicable to effect the same degree of perfection in finishing the cylinder wall engaging face as in finishing the sides. This is accounted for in part by the fact that the rings after being cut must be assembled in a special fixture and then transferred to an arbor on which they are held while being honed. This cannot be accomplished more perfectly than to within .001″ to .002″.

The following gives a comparison of the oil ring blank before nitriding (Fig. 4), after nitriding (Fig. 18) and in the finished form (Fig. 18a):

(1) Oil Ring Initial Outside Circumference Mounted on Male Form - - - - - - -	–OIOC–20.706″
Oil Ring Initial Radial Thickness - - - - - - - - -	–OIRT–.1725±.0005″
Oil Ring Initial Width (Same as CIW) - - - - - - -	–OIW–.0715±.0005″
(2) Oil Ring Nitrided Outside Circumference - - - - -	–OHOC–20.768″
Inner circumference of Oil Ring blank female - - -	–20.756″
OHOC (20.768″) minus OIOC (20.706″) - - - - - -	=.062″
average growth.	
Oil Ring Blank Nitrided Radial Thickness - - - - - -	–OHRT–.1730±.0005″
OHRT (.1730″ mean) minus OIRT (.1725 mean) - - - -	=.0005″
average growth	
Oil Ring Nitrided Width - -	–OHW–.0720″±.0005″
OHW (.0720″ mean) minus OIW (.0715″ mean) - - - -	=.0005″
average growth	

The remaining features of the oil ring are the same as for the compression ring with the exception of the cylinder wall engaging surface OPCF which is provided by removing a maximum of .0030″ from the arcuate nose portion OIF leaving a flat working surface of .010″ to .020″ in width. This removed portion is designated OZ in Fig. 18a. The matted surface is removed from the sides as indicated in dotted lines at OX to a depth of about .0009″ to provide a prime hard working surface, as well as a depth of case corresponding to the depth of case in the compression ring.

The significance of the above outlined small cross-sectional dimensions will now be apparent. By allowing the ring blanks to grow during nitriding into pressure engagement with the surrounding female form, I thus prevent any irregular distortions in the contour of the rings. Since there are no undulations or irregularities in the contour, it thus becomes necessary

to remove only the very minimum of the exterior surface of the nitrided rings in order to reach the underlying prime hard case structure required for contact with the piston groove and with the cylinder wall. For the same reason the underlying prime case is left with the maximum depth, and this depth is uniform throughout any particular surface.

A starting blank in the form of an endless ring has been found to have definite advantages, including: (1) it can be semi-finished by passing through double-disc grinders with no free ends requiring control; (2) full control of the radial pressure at the points, which is highly desirable, and which cannot be accomplished within the required close limits by any manufacturing technique heretofore known to the art with a split ring; (3) the sides of a piston ring with surfaces as hard as that after being subjected to the nitriding process can only be reduced in width by some sort of abrasive operation and during this operation, a solid endless piece can be more accurately finished to dimension than can a split piece; and (4) the last and final operation of removing the section JSR at the joint area can be done in group order which is advantageous to production and the maintenance of close tolerance in the relation of the ring ends.

While, as noted above, an endless ring has been disclosed as the blank to be subjected to the nitriding process, and this is the preferred procedure, it is also contemplated that this invention covers the use of a split ring blank (see Fig. 19). In practising the invention with a split ring blank, the same may be assembled with the ends engaging the proper dimensioned feather 56 within the fixture so as to provide the proper percentage of growth to take place before the ring completely fills the female form and exerts the required pressure thereagainst.

The same fundamental reaction can be accomplished without the use of a feather by using a split ring of the correct circumference leaving a clearance in the joint area to provide for the proper percentage of growth before the ends come into contact to create the desired pressure against the restraining female form. In addition, the ends of such a ring may be so angled as to cause the pressure at the periphery of the ring directly at the joint to become either negative or positive. In manufacturing a ring in accordance with the latter practice, it would be necessary to remove the ends in a similar manner to the removal of the joint area from the first and preferred endless blank.

Different percentages of the ultimate growth for pressure engagement with the female member may be used following actual contact of the outer periphery of the ring with the female member, ranging anywhere from 20% to 40% of the ultimate growth. It has been found, for example, that a particularly satisfactory Nitralloy "N" steel piston ring of 6.125" OD, 0.150" final radial thickness and 0.070" final width is obtained where seventy per cent. (70%) of the ultimate growth of the ring is allowed to take place before the outer periphery or face of the ring exerts an appreciable pressure against the surrounding wall of the female member. Thirty per cent. (30%) of the ultimate growth is thus employed after actual pressure engagement with the female member for preserving the contour and flatness of the final ring.

By following the above step of first forming the ring over the concentric male preshaping member 12, there results the advantage of having the ring grow substantially uniformly and identically into engagement with the female member 17 throughout the circumference, with the exception, of course, of the joint area JSR. This effects a substantially uniform pressure between the ring and the inner peripheral wall of the female member and substantially complete contact therewith. This is clearly distinguishable from taking a circular ring, compressing the same along one diameter to form a parabolic-like shape and inserting the same into the female member and following this with the nitriding step. This would result in the ring first contacting the female member at the area of the joint, as well as within the four to eight o'clock area at the start of the nitriding. During the nitriding, the ring would grow and gradually tend to fill the form from four o'clock and from eight o'clock in the direction of twelve o'clock but in the absence of the exertion of extreme pressures, the ring would never completely fill the form in the areas of two and ten o'clock where the radius is practically that of the engine cylinder diameter for which size the ring is intended. A further and very marked defect in this irregular growth in contact with the female form would be the fact that non-uniform radial pressures would be produced between the ring face and the female member, some of these pressures being so high that the nitriding atmosphere would be unable to gain access to the ring while in other places the atmosphere would gain access, thus resulting in a non-uniform nitrided case. It is essential that the alloy steel ring involved in the nitriding operation absorb the nitriding atmosphere uniformly over all

surfaces so as to prevent any uneven expansion or bi-metal effect which would result in not only a distorted contour but an out of flat condition which cannot be corrected.

If the nitrided case is appreciably thicker on the inner periphery of the ring than on the outer, when the joint piece JSR is cut out, the unstable condition will immediately evidence itself by the fact that the ring opens because of the high stress on the inner periphery; conversely, the opposite result takes place if the case on the outer periphery is of greater thickness than on the inner.

The same result as that obtained by the use of the male preshaping member can be obtained to lesser degree by pre-bending the ring blank in the area of from three to nine o'clock to a small radius in the areas of two and ten o'clock before placing the same in the female member.

The relation between the total nitrided case cross-sectional area and the total core cross-sectional area is critical in articles of small sections and has a definite relation to the total length of the piece, such, for example, as the herein-disclosed piston ring. This relation determines the amount of growth possible per unit of circumference during the nitriding furnace time cycle selected thus to obtain the requisite pressure against the female form and effect the desired physical characteristics. A satisfactory prime hard case thickness, for example, in an aircraft nitrided alloy steel piston ring of an O.D. 6.125" has been found to be .0055 to .0085", this being arrived at by manufacturing and engine operation requirements and conditions made necessary in order to obtain the desire high fatigue value and resiliency for high output, high-speed internal combustion engines.

It is believed that no one has heretofore appreciated the significance of the optimum relationship between the case and core area of a nitrided alloy steel piston ring and how to secure the same. From said relationship an accurate value can be established from which the percentage factor for determining the percentage of the total growth can be selected for predetermining the pressure that will be exerted against the female member during the nitriding operation. This relationship is, of course, a function of such value per unit of circumference or length of the piston ring.

To arrive at the proper value of growth per unit of length or circumference from which the total growth of an alloy steel article or alloy steel ring blank may be determined, the necessary specimens are subjected to a nitriding heat treatment, being measured accurately before and after the heating and from their individual growth an average value of growth is established per unit of length. With the length of the female interior circumference known, the required length or diameter of a ring blank of the same alloy steel as the specimens can be easily determined from the value previously established by specimen, in order to employ the proper percentage of the growth of the ring to exert the required pressure on the interior of the female form necessary to preserve the shape of the finished ring without adversely affecting the penetration of the gases to the face thereof.

My invention has been described above in considerable detail in connection with the specific maufacture of piston rings in order to show, with the requisite completeness, how to practise this process. From this it is believed that the application of my invention to the manufacture of other annular articles involving like problems will be apparent.

Referring to Fig. 20, one example of an alternative application of my invention is indicated schematically. A Nitralloy " N " alloy steel cylinder liner blank 57 is shown in position in spaced relation to the embracing furnace fixture 58 prior to heat treatment. As in the case of the above-described piston ring manufacture, the assembly will be placed in a nitriding furnace, such as 19 shown in Fig. 11, subjected to a nitriding atmosphere and selected temperature cycle for a selected time. The cylinder blank 57 will be caused to grow into radial pressure engagement with the surrounding wall of fixture 58 and this pressure engagement will be utilized to preserve the contour of the relatively thin sectioned cylinder blank during the formation thereon of the requisite nitrided case. Subsequently, the cylinder 57 is removed from the fixture, honed and otherwise finished for installation in an engine.

As above emphasized, the fact that the cylinder blank is preserved or held against distortion during nitriding it is only necessary to machine deep enough into the working surface of the cylinder to remove the matted surface therefrom, thus leaving a uniform depth of prime hard nitrided case of the order of .006" to .009". As in the case of a piston ring, the prevention of the formation of distortions in the contour makes this result possible.

While furnace fixture 58 is not disclosed in detail, it will be apparent that the same can be built in an equivalent manner to that of female member 17 of furnace fixture 13. This may include splitting the form as indicated at 58a, as

well as providing a cover member 58b, Belleville spring washers 58c and fastening cap screws 58d.

Referring to Fig. 21, there is indicated schematically the manner of practising my invention in nitriding an alloy steel Nitralloy "N" gear 61, the toothed annulus of which has a small axial dimension. Gear 61 is shown in spaced relation to the embracing furnace fixture, generally indicated by the reference 62, prior to the growth of the gear into pressure engagement with the form in a nitriding atmosphere. While the furnace fixture for receiving gear 61 has not been shown in detail, it will be apparent that the same may be constructed in a similar manner to the above described furnace fixture 58 and, as shown, may include a plurality of separable segments 71 and an embracing split ring 71a. This ring may be provided with a fastening means, such as that shown in Fig. 14.

Although I have described my invention in connection with Nitralloy "N" because of its unusual properties in practising this method, it is to be understood that in the broader aspects of my invention, I also contemplate the use of any alloy steel, as hereinbefore described, having the requisite properties.

Having now particularly described and ascertained the nature of my said invention and in what manner the same is to be performed, I declare that what I claim is:—

1. The method of maufacturing a piston ring, or other annular article having a small cross-sectional dimension, from a nitridable alloy steel which grows during the nitriding process, which method consists in forming a blank of the same shape but of smaller diameter than the final article, confining the blank in a furnace fixture having a shape and diameter corresponding to that of the final article, subjecting the blank to a nitriding atmosphere at a selected temperature and for a selected time so as to form a nitrided case on the blank, employing the growth of the blank to exert pressure against the fixture so as to prevent distortion of the article, and then removing the blank from the fixture.

2. The method according to Claim 1 in which the articles are formed of Nitralloy "N" steel.

3. The method according to Claim 2 in which the articles are piston rings.

4. The method of manufacturing a Nitralloy "N" piston ring from a split, normally circular piston ring blank, which comprises confining the blank within a furnace fixture which is larger in circumference than the blank, spreading the free ends of the blank sufficiently that when the blank is nitrided it will expand against the fixture, uniformly subjecting all surfaces of the blank to heat and a nitriding atmosphere at a temperature below the critical temperature of the Nitralloy "N," utilizing the growth property of the metal due to nitriding thereof to effect radial engagement with the interior of the fixture whilst the nitrided case is being formed, and removing the blank from the fixture.

5. The method according to Claim 4 in which the sides of the blanks are roughened and the blanks then stacked, one on the other, within the furnace fixture prior to nitriding.

6. A furnace fixture for use in carrying out the method according to any of claims 1 to 5, comprising a female furnace form provided with an internal contour corresponding to the external periphery of the article to be nitrided therein but permitting introduction of the article therein prior to nitriding, the fixture resisting the pressure exerted by growth of the article to preserve the contour of the latter against distortions, said fixture providing for the release of the article after nitriding.

7. A furnace fixture according to Claim 6 in which the furnace form is characterized by being composed of a split ring.

8. A furnace fixture according to Claim 6 in which a latch is provided to fasten and release the split furnace form.

9. A furnace fixture according to Claim 6 in which the inner periphery of the female furnace form is parabolic-like in cross-section.

10. A furnace fixture according to claims 6 and 9 in which there is employed a male preshaping furnace form having an external periphery concentric in shape to the parabolic-like inner periphery of the female form but spaced therefrom, the male form being effective to pre-shape the ring blank during the heating operation following which the ring is subsequently grown away—by nitriding—from the male member into pressure contact with the female member for preserving the contour of the ring against the formation therein of distortions.

11. A furnace fixture according to Claim 6 in which the female form is provided with a feather to be interposed between the ends of the split piston rings to be nitrided.

Dated the 12th day of September, 1945.

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Chartered Patent Agents,
75 & 77, Colmore Row, Birmingham, 3.

**Leamington Spa: Printed for His Majesty's Stationery Office, by the Courier Press.—1948.
Published at The Patent Office, 25, Southampton Buildings, London, W.C.2, from which copies, price 1s. 0d. each (inland) 1s. 1d. (abroad) may be obtained.**

Fig. 1

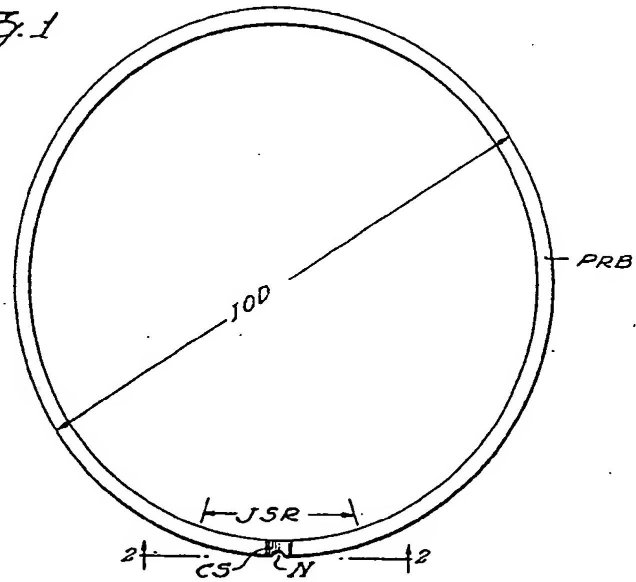


Fig. 2

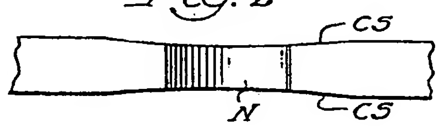


Fig. 16

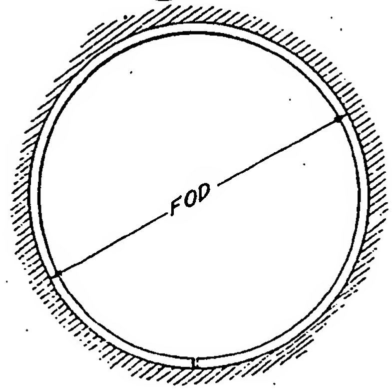


Fig. 3

Sec. of compression ring blank.

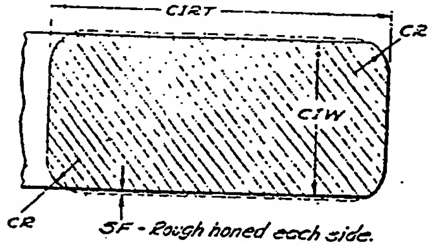


Fig. 4

Sec. of oil ring blank.

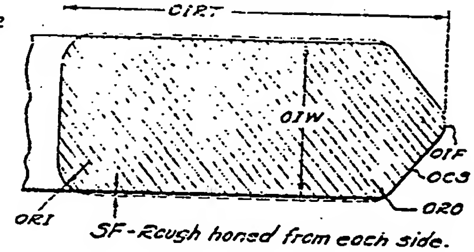


Fig. 17

After Nitriding.

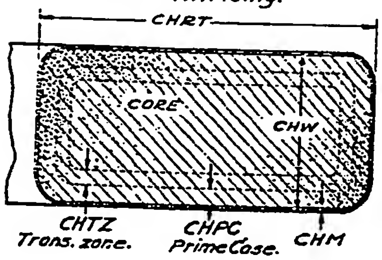


Fig. 18

After Nitriding.

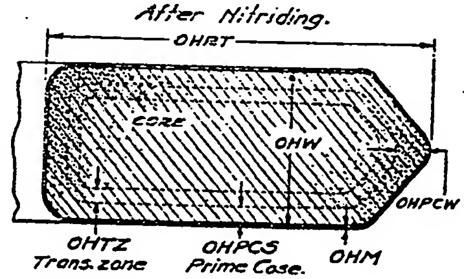


Fig. 17a

After finish hone.

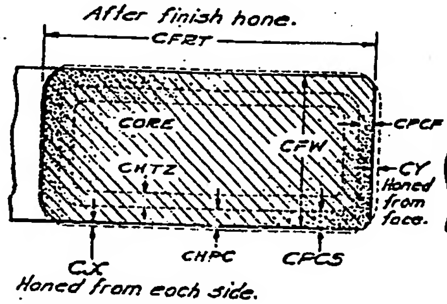
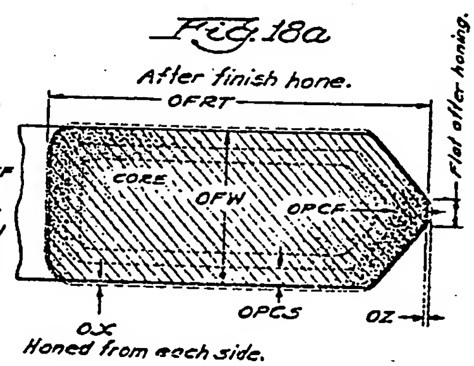


Fig. 18a

After finish hone.



607,701 COMPLETE SPECIFICATION

8 SHEETS

SHEET 1

Fig. 1

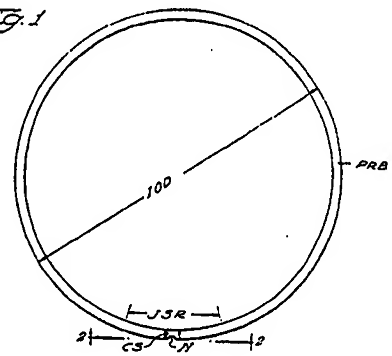


Fig. 2

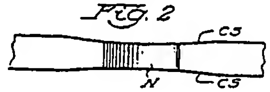
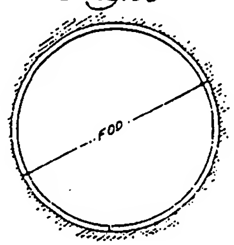


Fig. 16



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SHEET 2

Fig. 3

Sec. of compression ring blank.

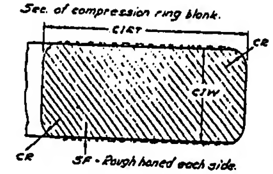

Fig. 11

Sec. of oil ring blank

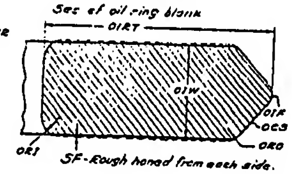

Fig. 17

After Nitriding.

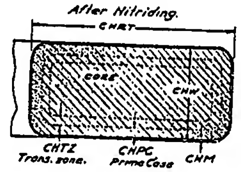

Fig. 18

After Nitriding.

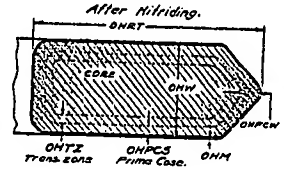

Fig. 17a

After finish hone.

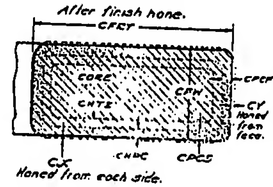

Fig. 18a

After finish hone.

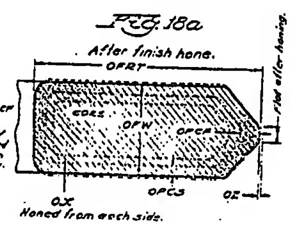

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Fig. 5

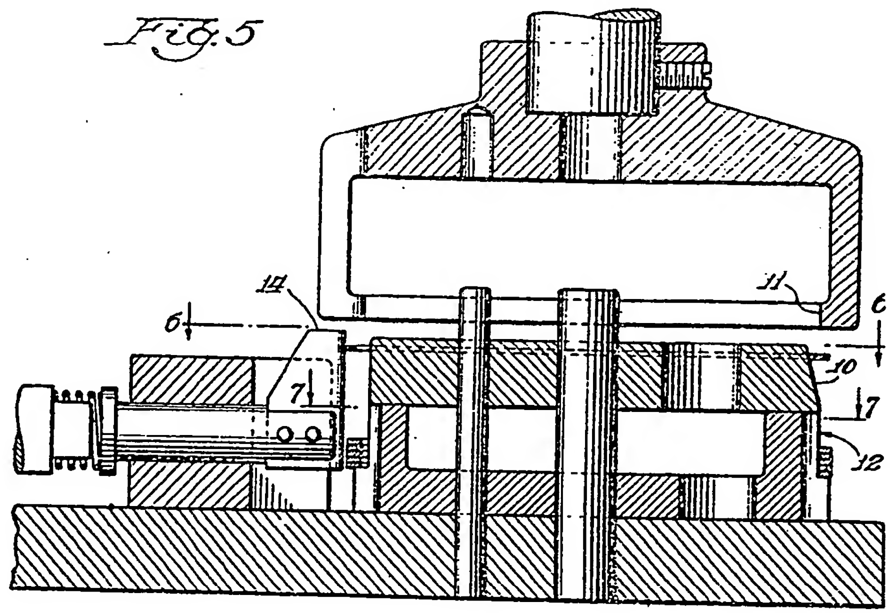
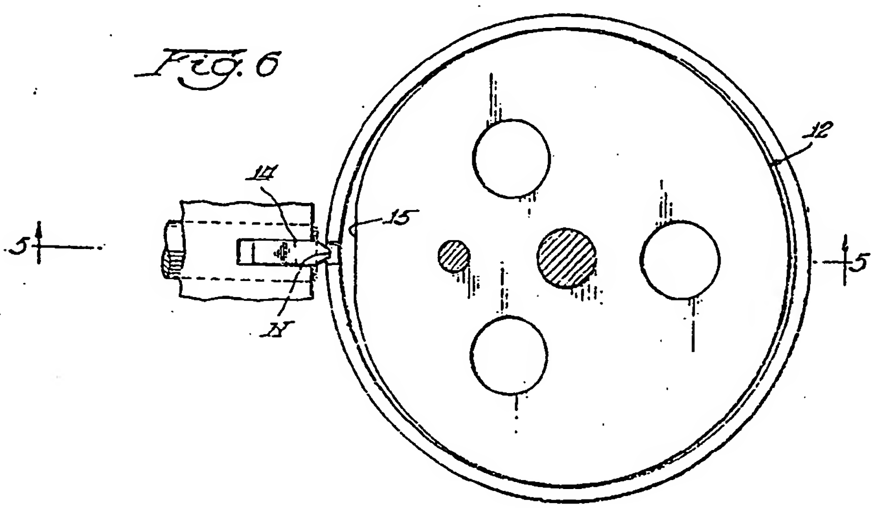
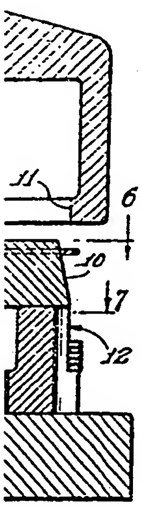


Fig. 6





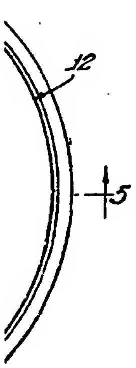


Fig. 7

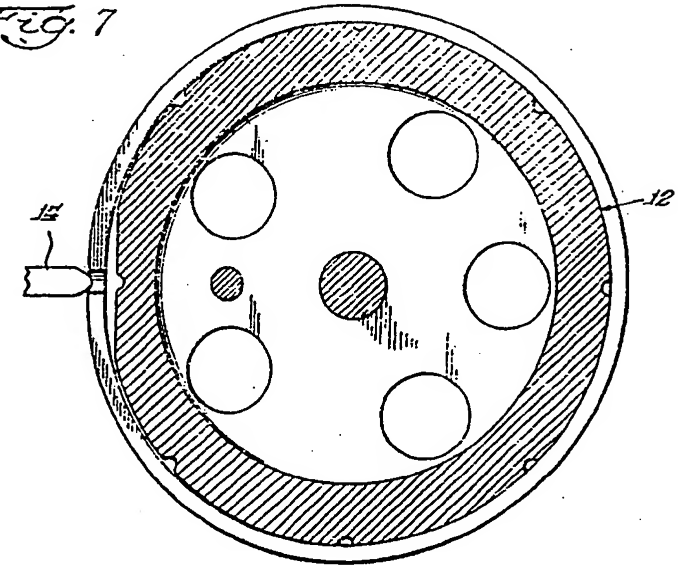


Fig. 8

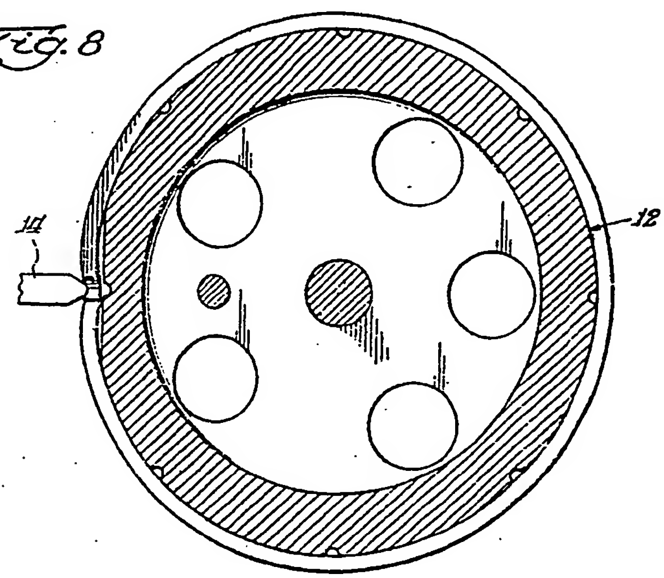


Fig. 5

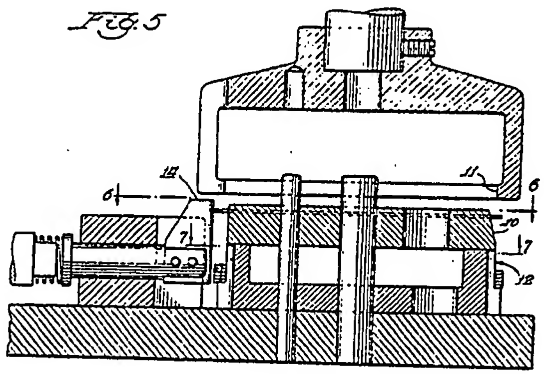


Fig. 6

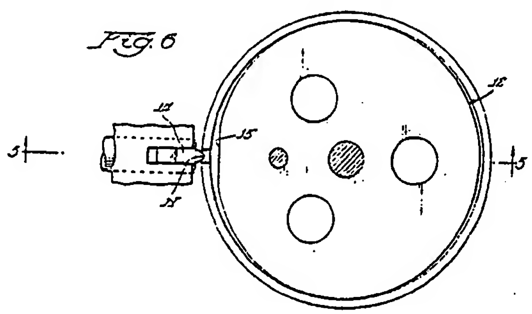


Fig. 7

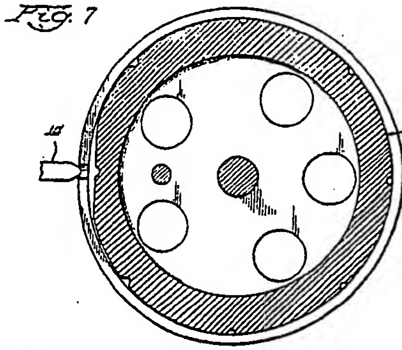


Fig. 8

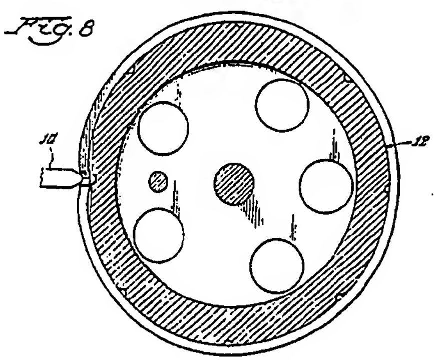


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Fig. 9

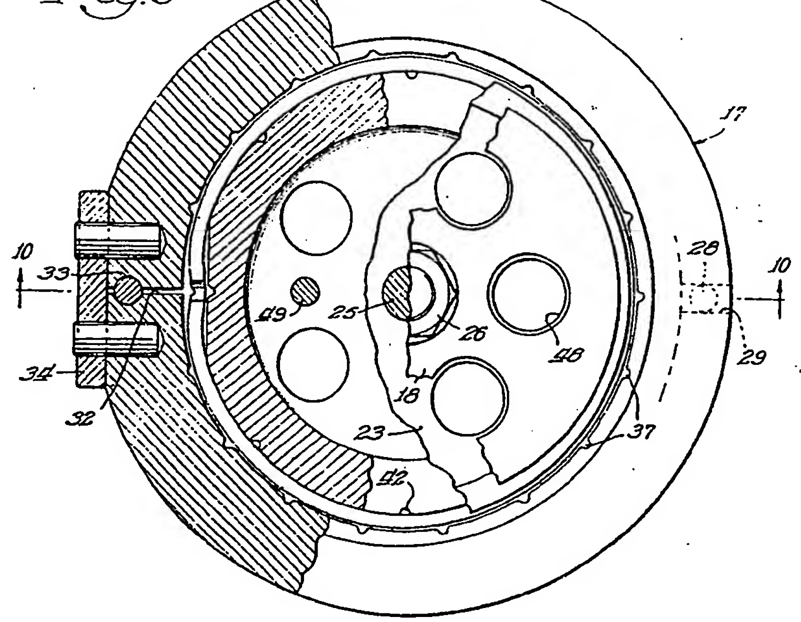

Fig. 10

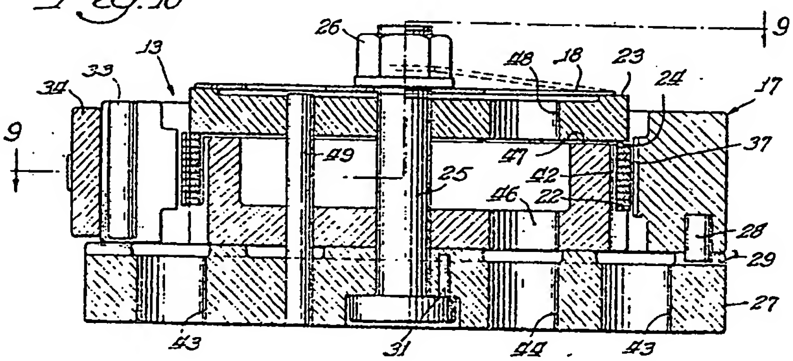

Fig. 11

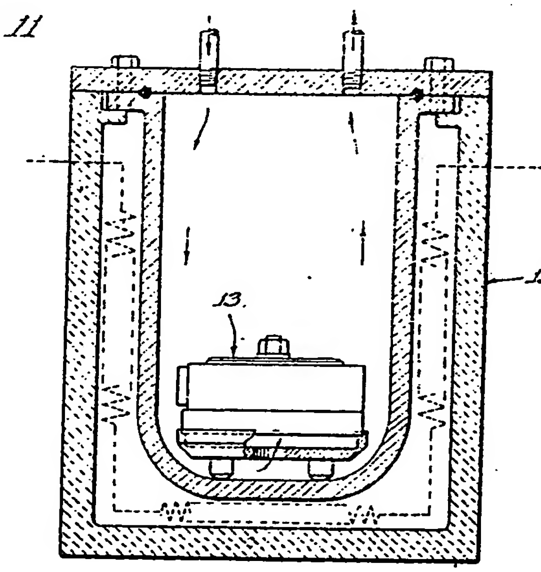

Fig. 12

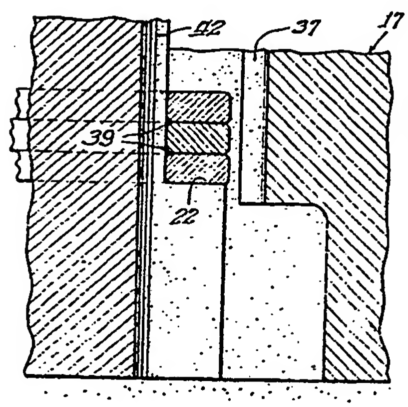

Fig. 13

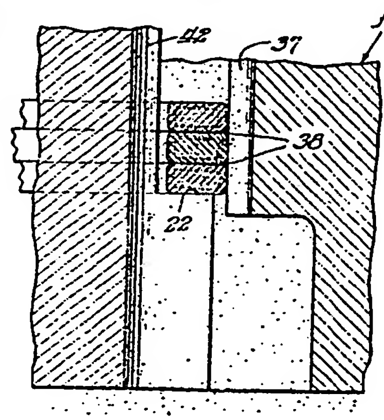

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Fig. 9

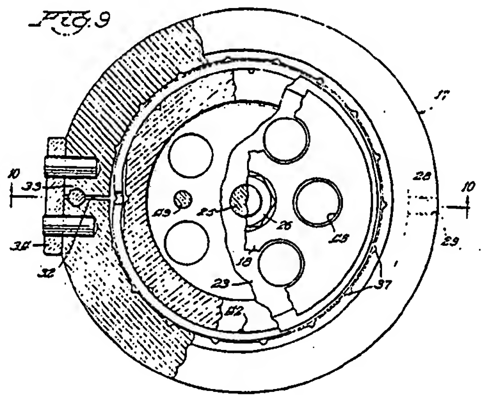

Fig. 10

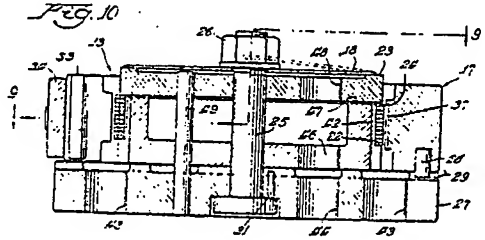

Fig. 11

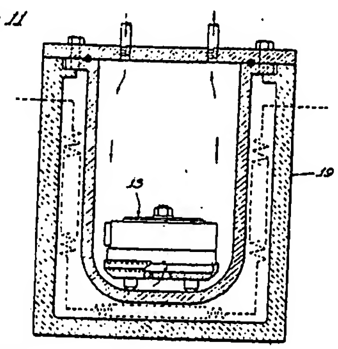

Fig. 12

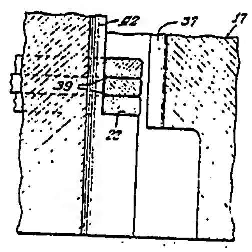

Fig. 13

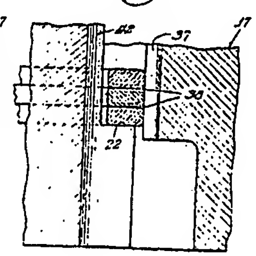

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Fig.14

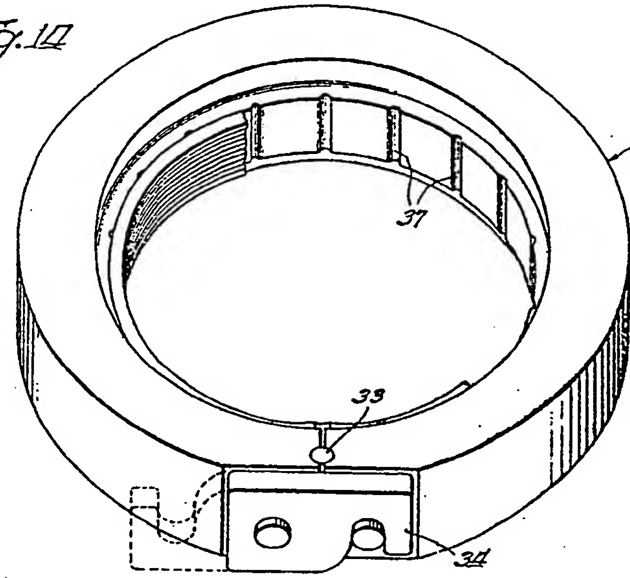
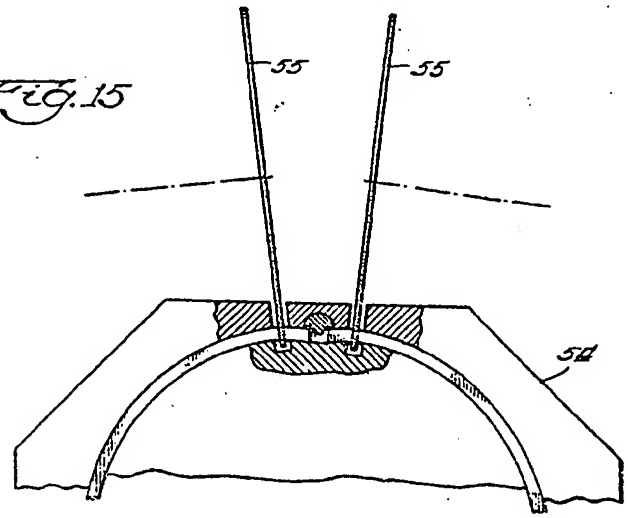


Fig.15



7

Fig. 19

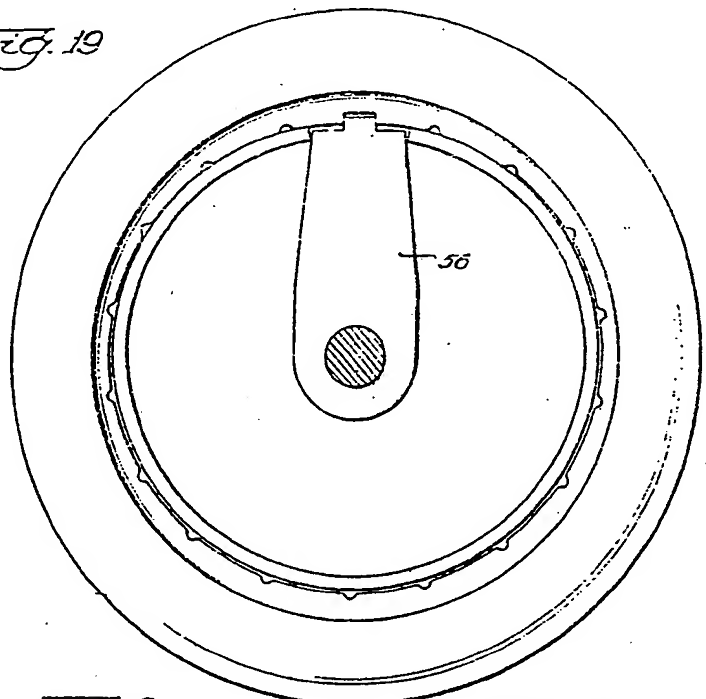


Fig. 20

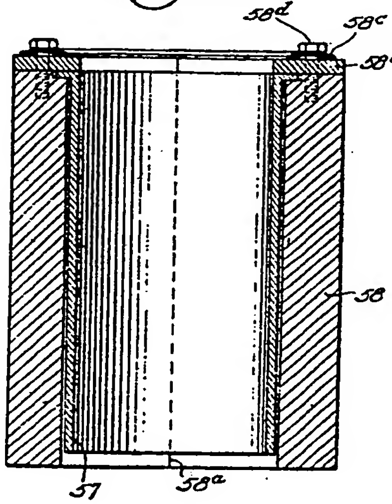


Fig. 21

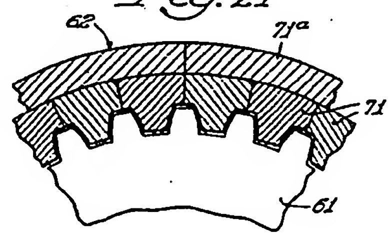


Fig. 10

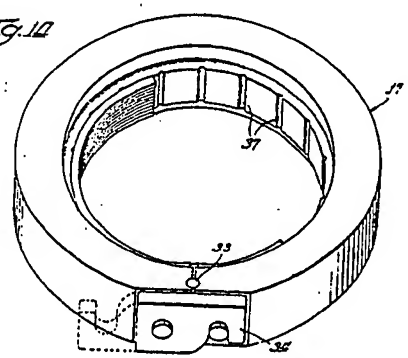


Fig. 15

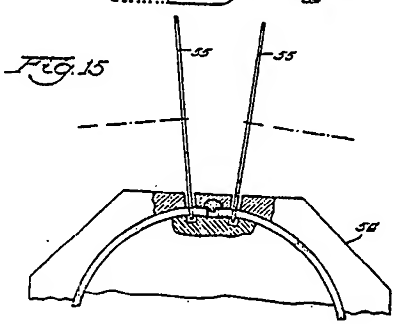


Fig. 19

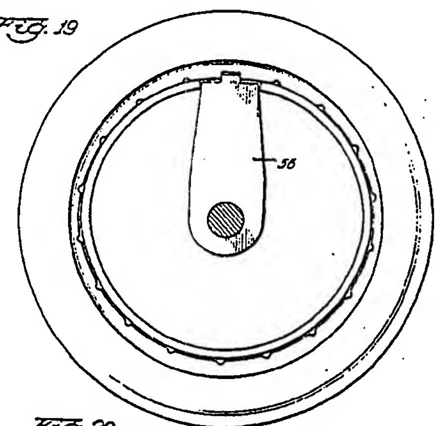
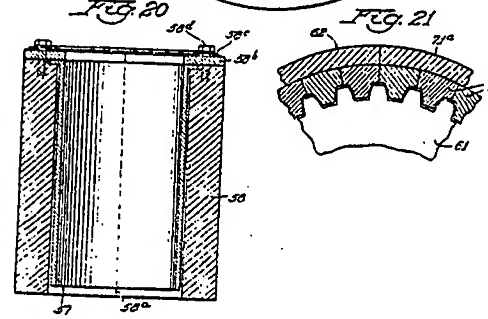


Fig. 20

Fig. 21



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